PCT

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05/23/01

FORM PTO-1390 (REV. 10-2000) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE		ATTORNEY'S DOCKET NUMBER S1022/8315
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		U S APPLICATION NO (If known, see 37 CFR 1 5) 09/856738
INTERNATIONAL APPLICATION NO. PCT/EP99/09475	INTERNATIONAL FILING DATE 24 November 1999	PRIORITY DATE CLAIMED 24 November 1998

TITLE OF INVENTION
MULTISTANDARD DMT DSL TRANSMISSION SYSTEM

APPLICANT(S) FOR DO/EO/US MESTDAGH, Denis J.G., FARGERE, Gerard and ISAKSSON, Mikael

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☐ This is an express request to promptly begin national examination procedures (35 U.S.C. 371(f)).
4. ☐ The US has been elected by the expiration of 19 months from the earliest claimed priority date (PCT Article31).
5. ☐ A copy of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☒ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ has been transmitted by the International Bureau.
7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3)).
   a. ☐ are attached hereto (required only if not transmitted by the International Bureau).
   b. ☐ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☐ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(C)(5)).

Items 11. To 16. Below concern document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A FIRST preliminary amendment.
14. ☐ A SECOND or SUBSEQUENT preliminary amendment.
15. ☐ A substitute specification.
16. ☐ A change of power of attorney and/or address letter.
17. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C.1.821-1.825.
18. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
19. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
20. ☒ Other items or information: Title page of WO 00/31938

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JC18 Rec'd PCT/PTO 23 MAY 2001

U.S. APPLICATION NO (if known, see 37 CFR 1.5) 09/856738	INTERNATIONAL APPLICATION PCT/SE99/02116	ATTORNEY'S DOCKET NUMBER S1022/8315

21. ☒ The following fees are submitted:	CALCULATIONS	PTO USE ONLY
BASIC NATIONAL FEE (37 CFR 1.492(a)(1)-(5)):		
Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO $1000.00		
International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO $860.00		
International preliminary examination fee (37 CFR 1.482) not paid to USPTO but but international search fee paid to USPTO (37 CFR 1.445(a)(2)).paid to USPTO $710.00		
International preliminary examination fee paid to USPTO (37 CFR 1.482) But all claims did not satisfy provisions of PCT Article 33(1)-(4) $690.00		
International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) $100.00		
ENTER APPROPRIATE BASIC FEE AMOUNT = $860.00		
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total Claims	6 - 20 =	0	X $18.00	$ 0	
Independent Claims	1 - 3 =		X $80.00	$	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+$270.00	$	
TOTAL OF ABOVE CALCULATIONS =				$ 860.00	
☐ Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by ½.				$	
SUBTOTAL =				$ 860.00	
Processing fee of $130.00 for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)).				$	
TOTAL NATIONAL FEE =				$ 860.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate coversheet (37 CFR 3.28, 3.31). $40.00 per property +				$	
TOTAL FEES ENCLOSED =				$ 860.00	
				Amount to be: refunded	$
				charged	$

a. ☒ A check in the amount of $ 860.00 to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. ____________ In the amount of $____________ To cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 23/2825. A duplicate of this sheet is enclosed.

d. ☐ Fees are to be charged to a credit card. WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO

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Express Mail Label No. EL840357000US
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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: MESTDAGH, Denis J.G., FARGERE, Gerard and ISAKSSON, Mikael
Serial No.: Unassigned
Filing Date: Herewith
For: MULTISTANDARD DMT DSL TRANSMISSION SYSTEM

Examiner: Unassigned
Art Unit: Unassigned

Commissioner for Patents
Box Patent Application (DO/EO/US)
Washington, D.C. 20231

PRELIMINARY AMENDMENT

Sir/Madam:

Prior to examination, please amend the above-identified application as follows:

IN THE SPECIFICATION

Please replace the bottom paragraph on page 1.

Current VDSL standardization proposals contemplate the use of frequencies up to 11.04 mhz..

Please replace the second paragraph on page 4, lines 4-6.

An object of the invention is to provide a transmission system which allows a single modem to exploit many DSL standards with a low complexity.

Please replace the paragraphs on page 6, commencing on line 12 through line 27, as shown.

As illustrated by the spectrum of figure 5, an aspect of the invention is to extend the spectrum of an ADSL-Lite transmission in order to approach the maximum frequency used in conventional VDSL systems, i.e. 11.04 MHz. The number of tones should be a power of 2 to be compatible with IFFT and FFT circuits of conventional architecture. In the embodiment of figure 5, the invention uses either 2048 or 4096 tones spaced by 4.3125 KHz. By using 2048 tones, the

last tone has a frequency of 8.832 MHz, whereby the transmission rate is slightly reduced with respect to a system which uses tones up to the design limit of 11.04 MHz. In fact, this does not significantly reduce the transmission rate, because, in most cases, the last tones near 11.04 MHz can only convey very little information or no information at all due to a large attenuation.

However, in case the transmission conditions are excellent, the invention allows the use of 4096 tones spaced by 4.3125 KHz, whereby the last tone has a frequency of 17.664 MHz.

Please replace the first last paragraph on page 6 as shown.

To transmit data according to the ADSL or ADSL-Lite standards with the above solution, it is sufficient to just use the first 128 or 256 tones by providing corresponding coefficients to the first frequency domain inputs of the IFFT circuit, and by zeroing the remaining inputs. In reception mode, the FFT circuit will extract and provide to its first 128 or 256 outputs the desired coefficients, the remaining coefficients being zero.

Please replace the first two paragraphs on page 7 as shown.

The only modification needed to the transmission system is to provide zero-padding and depadding circuitry for adapting the low rate of the effective digital data transmission to the fixed high operation speed of the IFFT and FFT circuits.

A drawback of such a system is however that it operates at the highest frequency, adapted to the highest transmission rate, whereas the effective data transmission rate may be much lower. This causes unnecessary extra power consumption by the analog front-end.

Please replace the paragraph on page 8 commencing on line 16 through line 26 as shown.

To avoid this, the invention provides IFFT and FFT circuits of variable size, which is equivalent to making variable the number of tones used by the system. Then, if the size of the IFFT an FFT circuits is reduced by a factor k, it is sufficient to reduce the operating speed of the IFFT and FFT circuits by the same factor k to maintain the spacing between the tones. In the example of figure 6, the number of tones will be reduced by a factor 8, whereby the IFFT and FFT circuits would operate 8 times slower, i.e. at 2.208 MHz, the same frequency as analog-to-digital converter 24. Decimator 30 and interpolator 32 are unnecessary.

Express Mail Label No. EL840357000US
Attorney's Docket No. S1022/8315
Date Mailed: May 23, 2001

Please replace the paragraph on page 11 which commences on line 4 through line 17 as shown.

It is designed, for VDSL-TDD and VDSL "Zipper" modems, that the tones will be used in an initial phase to transmit modem identification signatures. In other words, a transmitting modem, before establishing a communication, will send a signal conveying specific tones or "bare" carriers, chosen depending on the standard among the possible tones. The receiving modem will detect which tones are present in the signal and identify the standard accordingly. For this purpose, the receiving modem should be "tuned-in" on the transmitting modem from the start, i.e. use at least the tones used by the transmitting modem. Every 8th or every 4th tone of a VDSL Zipper modem is used by a VDSL-TDD modem, whereby such an identification phase is possible in both directions if only the 256 or 512 tones of the VDSL-TDD system are used for the signatures.

<ins>IN THE CLAIMS</ins>

1. (Amended) A digital subscriber line transmission system using QAM modulation on N=2048 or 4096 tones spaced by 4.3125 kHz, including at least two operating modes:

a VDSL standard operating mode where all N tones are used to convey significant values; and

an ADSL standard operating mode where only the first n=128 or 256 among the N tones are usd to convey significant values.

2. (Amended) The system of claim 1, comprising, on the transmitter side:

an inverse fast Fourier transform circuit having N frequency domain value inputs corresponding to said tones, among which only the first receive values corresponding to the n used tones, the remaining inputs being zoered,

a decimator providing one sample for every r samples output by the inverse fast Fourier transform circuit, with r = N/n, and

a digital-to-analog converter coupled between the decimator and a subscriber line.

Express Mail Label No. EL840357000US
Attorney's Docket No. S1022/8315
Date Mailed: May 23, 2001

3. (Amended) The system of claim 2, comprising, on the receiver side:

an analog-to-digital converter sampling the signal on the subscriber line at a frequency F/r, where F is the operating frequency of the inverse fast Fourier transform circuit;

an interpolator generating samples at frequency F from the samples provided by the analog-to-digital converter; and

a fast Fourier transform circuit operating at frequency F and receiving the samples from the interpolator through a time domain equalizer;

wherein, when all N tones are used, the time domain equalizer is bypassed.

4. (Amended) The system of claim 1 comprising, at a transmitter side, an inverse fast Fourier transform circuit having:

a number of frequency domain inputs selectable at least among values N and n; and

an operating frequency selectable at least among two values F and fn proportional, respectively, to the frequency of the last of the N tones and the last of the n tones.

5. (Amended) The system of claim 4, comprising, at a receiver side, a fast Fourier transform circuit having:

a number of frequency domain outputs selectable at least among values N and n; and

an operating frequency selectable at least among values F and fn.

6. (Amended) The system of claim 5, wherein each of the inverse fast Fourier transform and fast Fourier transform circuits includes five radix-4 stages and a last stage having a radix selectable among 2 and 4, all connected to operate in pipeline mode, the desired number of frequency domain inputs or outputs of the circuit being selectable by passing an appropriate number of stages and by selecting the radix of the last stage.

Express Mail Label No. EL840357000US
Attorney's Docket No. S1022/8315
Date Mailed: May 23, 2001

REMARKS

This is a preliminary amendment in which the claims have been amended to place them in better form before initial examination by the Examiner. In addition, changes have been made to the specification to improve readability. No new matter has been introduced by these changes. Favorable action is hereby earnestly solicited.

Respectfully submitted,

By: ______________________

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Attorney's Docket No. S1022/8315
Dated: May 23, 2001

Express Mail Label No. EL840357000US
Attorney's Docket No. S1022/8315
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AMENDED SPECIFICATION SHOWING THE AMENDMENTS

Please replace the bottom paragraph on page 1.

Current VDSL standardization proposals [devise] contemplate the use of frequencies up to 11.04 mhz.

Please replace the second paragraph on page 4, lines 4-6.

An object of the invention is to provide a transmission system which [will allow] allows a single modem to exploit many DSL standards with a low complexity.

Please replace the paragraphs on page 6, commencing on line 12 through line 27, as shown.

As illustrated by the spectrum of figure 5, an aspect of the invention is to extend the spectrum of an ADSL-Lite transmission in order to approach the maximum frequency used in conventional VDSL systems, i.e. 11.04 MHz. The number of tones should be a power of 2 to be compatible with IFFT and FFT circuits of conventional architecture. In the embodiment of figure 5, the invention uses either 2048 or 4096 tones spaced by 4.3125 KHz. By using 2048 tones, the last tone has a frequency of 8.832 MHz, whereby the transmission rate is slightly reduced with respect to a system which uses tones up to the [devised] design limit of 11.04 MHz. In fact, this does not significantly reduce the transmission rate, because, in most cases, the last tones near 11.04 MHz can only convey very little information or no information at all due to a large attenuation.

However, in case the transmission conditions are excellent, the invention [provides] allows the use of 4096 tones spaced by 4.3125 KHz, whereby the last tone has a frequency of 17.664 MHz.

Please replace the first last paragraph on page 6 as shown.

To transmit data according to the ADSL or ADSL-Lite standards with the above solution, it is sufficient to just use the first 128 or 256 tones by providing corresponding coefficients to the first frequency domain inputs of the IFFT circuit, and by zeroing the remaining inputs. In

reception mode, the FFT circuit will extract and provide to its first 128 or 256 outputs the [wanted] desired coefficients, the remaining coefficients being zero.

Please replace the first two paragraphs on page 7 as shown.

The only modification [to bring to] needed to the transmission system is to provide zero-padding and depadding circuitry for adapting the low rate of the effective digital data transmission to the fixed high operation speed of the IFFT and FFT circuits.

A drawback of such a system is however that it operates at the highest frequency, adapted to the highest transmission rate, whereas the effective data transmission rate may be much lower. This causes unnecessary extra power consumption [of] by the analog front-end.

Please replace the paragraph on page 8 commencing on line 16 through line 26 as shown.

To avoid this, the invention provides IFFT and FFT circuits of variable size, which is equivalent to making variable the number of tones used by the system. Then, if the size of the IFFT an FFT circuits is reduced by a factor k, it is sufficient to reduce the operating speed of the IFFT and FFT circuits by the same factor k [for maintaining] to maintain the spacing between the tones. In the example of figure 6, the number of tones will be reduced by a factor 8, whereby the IFFT and FFT circuits would operate 8 times slower, i.e. at 2.208 MHz, the same frequency as analog-to-digital converter 24. Decimator 30 and interpolator 32 are unnecessary.

Please replace the paragraph on page 11 which commences on line 4 through line 17 as shown.

It is [devised] designed, for VDSL-TDD and VDSL "Zipper" modems, that the tones will be used in an initial phase to transmit modem identification signatures. In other words, a transmitting modem, before establishing a communication, will send a signal conveying specific tones or "bare" carriers, chosen depending on the standard among the possible tones. The receiving modem will detect which tones are present in the signal and identify the standard accordingly. For this purpose, the receiving modem should be "tuned-in" on the transmitting modem from the start, i.e. use at least the tones used by the transmitting modem. Every 8th or every 4th tone of a VDSL Zipper modem is used by a VDSL-TDD modem, whereby such an

Express Mail Label No. EL840357000US
Attorney's Docket No. S1022/8315
Date Mailed: May 23, 2001

identification phase is possible in both directions if only the 256 or 512 tones of the VDSL-TDD system are used for the signatures.

Express Mail Label No. EL840357000US
Attorney's Docket No. S1022/8315
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AMENDED CLAIMS SHOWING THE AMENDMENTS

1. (Amended) A digital subscriber line transmission system using QAM modulation on N=2048 or 4096 tones spaced by 4.3125 kHz, [characterized in that it has] including at least two operating modes:

[-] a VDSL standard operating mode where all N tones are used to convey significant values; and

[-] an ADSL standard operating mode where only the first n=128 or 256 among the N tones are usd to convey significant values.

2. (Amended) The system of claim 1, [characterized in that it comprises] comprising, on the transmitter side:

[-] an inverse fast Fourier transform [(IFFT)] circuit [(12)] having N frequency domain value inputs corresponding to said tones, among which only the first receive values corresponding to the n used tones, the remaining inputs being zeroed,

[-] a decimator [(30)] providing one sample for every r samples output by the [IFFT] inverse fast Fourier transform circuit, with r = N/n, and

[-] a digital-to-analog converter [(14)] coupled between the decimator and a subscriber line [(10)].

3. (Amended) The system of claim 2, [characterized in that it comprises] comprising, on the receiver side:

[-] an analog-to-digital converter [(24)] sampling the signal on the subscriber line at a frequency F/r, where F is the operating frequency of the [IFFT] inverse fast Fourier transform circuit;

[-] an interpolator [(32)] generating samples at frequency F from the samples provided by the analog-to-digital converter; and

[-] a fast Fourier transform [(FFT)] circuit operating at frequency F and receiving the samples from the interpolator through a time domain equalizer [(26)];

wherein, when all N tones are used, the time domain equalizer is bypassed.

4. (Amended) The system of claim 1 comprising, at a transmitter side, an [IFFT] inverse fast Fourier transform circuit [(12)] having:

[-] a number of frequency domain inputs selectable at least among values N and n; and

[-] an operating frequency selectable at least among two values F and fn proportional, respectively, to the frequency of the last of the N tones and the last of the n tones.

5. (Amended) The system of claim 4, [characterized in that it comprises] comprising, at a receiver side, [an FFT] a fast Fourier transform circuit [(20')] having:

[-] a number of frequency domain outputs selectable at least among values N and n; and

[-] an operating frequency selectable at least among values F and fn.

6. (Amended) The system of claim 5, [characterized in that] wherein each of the [IFFT] inverse fast Fourier transform and [FFT] fast Fourier transform circuits includes five radix-4 stages [(34)] and a last stage [(36)] having a radix selectable among 2 and 4, all connected to operate in pipeline mode, the desired number of frequency domain inputs or outputs of the circuit being selectable by passing an appropriate number of stages and by selecting the radix of the last stage.

09/856738
JC18 Rec'd PCT/PTC 23 MAY 2001

3/PRTS

MULTISTANDARD DMT DSL TRANSMISSION SYSTEM

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to discrete multitone (DMT) based digital subscriber line (DSL) transmission systems which allow high speed communication on twisted pair telephone lines. The invention relates more specifically to a VDSL (Very high speed DSL) system which can be used with several existing or forthcoming standards.

Discussion of the Related Art

Figure 1 shows the spectrum of a signal transmitted according to the ADSL and ADSL-Lite (asymmetric DSL) standards. The ADSL standard uses quadrature amplitude modulation (QAM) on each of 256 tones, the tones being equally spaced by 4.3125 kHz. Thus, as shown, the last tone has a frequency of 1.104 MHz. The ADSL-Lite standard only uses the first 128 tones.

As shown, a gap is left at the beginning of the spectrum for "plain old telephone services" (POTS).

According to the ADSL standards, most of the tones are used for reception, the few remaining tones being used for transmission, hence the term "asymmetric DSL".

Current VDSL standardization proposals devise the use of frequencies up to 11.04 MHz.

Figure 2 shows the spectrum of a signal transmitted by a conventional VDSL time domain duplexing (TDD) system such as described in "VDSL Alliance SDMT VDSL Draft Standard Proposal", ETSI STC/TM6, 973T13R0, Lannion, France, September 29-October 3, 1997. This system uses 256 or 512 tones spaced, respectively, by 43 or 21.5 kHz. The last tone has a frequency of 11.04 MHz. All the tones are used for a same transmission direction at one time, the transmission direction being switched every other transmitted symbol.

Figure 3 shows the spectrum a signal transmitted by a conventional VDSL "Zipper" system as disclosed in patent application WO 97/06619. It uses 2048 tones spaced by 5.375 kHz, the last tone also having a frequency of 11.04 MHz. In this system, the tones used for transmission and for reception are chosen dynamically in order to cancel near-end crosstalk and near-end echoes.

Figure 4 very schematically shows a DSL transmission system at one end of a telephone line 10. An inverse fast Fourier transform (IFFT) circuit 12 receives N complex frequency domain coefficients, where N is the number of tones used by the system, i.e. 128 or 256 for the ADSL standards, 256 or 512 for the VDSL TDD system, and 2048 for the VDSL Zipper system. The IFFT circuit 12 generates, for each set of N coefficients, a time domain symbol. A symbol is thus the sum of N sinusoidal subcarriers of different frequencies corresponding respectively to the tones. The amplitude and phase of each subcarrier is determined by the corresponding frequency domain coefficient received by the IFFT circuit. The symbols are processed by a digital-to-analog converter 14 and a low-pass filter 16 and then transferred onto telephone line 10 through a hybrid line interface 18.

A cyclic prefix and a cyclic suffix are added to the symbol output by IFFT circuit 12 at 19. The cyclic prefixes are intended to eliminate intersymbol interference in the far-end receiver by providing a guard period during which the

propagation transients of the line may decay. The cyclic suffix is intended to cancel the effects of the sampling of discontinuities in near-end echoes.

Line interface 18 also receives incoming symbols from line 10. These incoming symbols are provided to a fast Fourier transform (FFT) circuit 20 through a low-pass filter 22, an analog-to-digital converter 24 and, if necessary, through a time domain equalizer 26.

The above mentioned cyclic prefix, in order to accomplish its role, has a minimum length independent of the symbol length. In DSL systems using a relatively low number of tones, such as ADSL and VDSL TDD, the transmitted symbols are short, whereby the minimum length of the cyclic prefix is so long that it causes a substantial efficiency loss in the data transmission. In this case, the cyclic prefix is chosen shorter than necessary and it is the role of the time domain equalizer 26 to complement the short cyclic prefixes in the elimination of the intersymbol interference.

In DSL systems using a large number of tones, such as in the VDSL Zipper system, the generated symbols are so long that the cyclic prefixes can be chosen at the necessary length without substantially affecting the efficiency of the transmission. In such systems, the time domain equalizer 26 is omitted.

Moreover, in a VDSL TDD system, since the IFFT circuit and FFT circuit are never used at the same time, it is a single circuit which performs both functions.

The IFFT and FFT circuits operate at least at twice the frequency of the last tone used by the system, i.e. 1.104 MHz for ADSL-Lite, 2.208 MHz for ADSL, and 22.08 MHz for the known VDSL systems.

It is clear that the ADSL standards and forthcoming VDSL standards differ in many ways (the number of used tones, the spacing between the tones, the operation frequency of the IFFT and FFT circuits...), which is likely to increase the

number of types of modems capable of exploiting these standards.

SUMMARY OF THE INVENTION

An object of the invention is to provide a transmission system which will allow a single modem to exploit many DSL standards with a low complexity.

To achieve this and other objects, the invention provides a digital subscriber line transmission system using QAM modulation on several equally spaced discrete tones. At a high transmission rate, the system uses N = 4096/p tones spaced by 4.3125 kHz, where p is a power of 2 (p = 1, 2, 4, 8...).

According to an embodiment of the invention, for transmitting at a low transmission rate according to an ADSL standard, only the first n = 128 or 256 tones are used with p = 1.

According to an embodiment of the invention, the system comprises, on the transmitter side, an inverse fast Fourier transform circuit having N frequency domain value inputs corresponding to said tones, among which only the first receive values corresponding to the n used tones, the remaining inputs being zeroed, a decimator providing one sample for every r samples output by the IFFT circuit, with r = N/n, and a digital-to-analog converter coupled between the decimator and a subscriber line.

According to an embodiment of the invention, the system comprises, on the receiver side, an analog-to-digital converter sampling the signal on the subscriber line at a frequency F/r, where F is the operating frequency of the IFFT circuit; an interpolator generating samples at frequency F from the samples provided by the analog-to-digital converter; and a fast Fourier transform circuit operating at frequency F and receiving the samples from the interpolator through a time domain equalizer. When all N tones are used, the time domain equalizer is bypassed.

According to an embodiment of the invention, the system is applicable to a standard using n first tones among the N tones, where n is a power of 2. It comprises, at a transmitter side, an IFFT circuit having a number of frequency domain inputs selectable at least among values N and n; and an operating frequency selectable at least among two values F and fn proportional, respectively, to the frequency of the last of the N tones at the high transmission rate, and to the last of the n tones.

According to an embodiment of the invention, the system comprises, at a receiver side, an FFT circuit having a number of frequency domain outputs selectable at least among values N and n; and an operating frequency selectable at least among values F and fn.

According to an embodiment of the invention, each of the IFFT and FFT circuits includes five radix-4 stages and a last radix-2 or radix-4 stage connected to operate in pipeline mode, the desired number of frequency domain inputs or outputs of the circuit being selected by bypassing an appropriate number of stages and by selecting the radix of the last stage.

The foregoing and other objects, features, aspects and advantages of the invention will become apparent from the following detailed description of embodiments, given by way of illustration and not of limitation with reference to the accompanying drawings.

Brief Description of the Drawings

Figure 1, previously described, shows a spectrum of signals transmitted according to the ADSL and ADSL-Lite standards;

figure 2, previously described, shows a spectrum of signals transmitted in a conventional VDSL TDD system;

figure 3, previously described, shows a spectrum of signals transmitted in a conventional VDSL "Zipper" system;

figure 4 partially and schematically shows a DSL transmission system;

figure 5 shows a spectrum of signals transmitted in an embodiment of a VDSL system according to the invention;

figure 6 partially and schematically shows an embodiment of a VDSL system according to the invention adaptable to the ADSL and ADSL-Lite standards;

figure 7 schematically shows an embodiment of an IFFT circuit used in a VDSL system according to the invention; and

figure 8 schematically shows an architecture of a universal DSL modem according to the invention, incorporating IFFT and FFT circuits according to figure 7.

Detailled Description

As illustrated by the spectrum of figure 5, an aspect of the invention is to extend the spectrum of an ADSL-Lite transmission in order to approach the maximum frequency used in conventional VDSL systems, i.e. 11.04 MHz. The number of tones should be a power of 2 to be compatible with IFFT and FFT circuits of conventional architecture. In the embodiment of figure 5, the invention uses 4096 tones spaced by 4.3125 kHz, whereby the last tone has a frequency of 17.664 MHz. By using 2048 tones, the last tone would have a frequency of 8.832 MHz, whereby the transmission rate is significantly reduced with respect to a system which uses tones up to the devised limit of 11.04 MHz.

An aspect of the invention is to note that such a system, using 2048 tones or 4096 tones, is immediately usable with any standard using fewer tones at the same spacing, such as 128 or 256 (ADSL-Lite, ADSL).

To transmit data according to the ADSL or ADSL-Lite standards with the above solution, it is sufficient to just use the first 128 or 256 tones by providing corresponding coefficients to the first frequency domain inputs of the IFFT circuit, and by zeroing the remaining inputs. In reception mode, the FFT circuit will extract to its first 128 or 256 outputs the wanted coefficients, the remaining coefficients being zero.

The only modification to bring to transmission system is to provide zero-padding and depadding circuitry for adapting the low rate of the effective digital data transmission to the fixed high operation speed of the IFFT and FFT circuits.

A drawback of such a system is however that it operates at the highest frequency, adapted to the highest transmission rate, whereas the effective data transmission rate may be much lower. This causes unnecessary extra power consumption of the analog front-end.

Figure 6 schematically shows an embodiment of a transmission system operating as described above and additionally provided with circuitry for reducing the power consumption. As an example, the system is intended to operate with 4096 tones and is used with the ADSL standard, which will only use 256 tones. As shown, only the first 256 inputs of IFFT circuit 12 and the 256 first outputs of FFT circuit 20 are used.

The IFFT and FFT circuits operate at 35.228 MHz, i.e. twice the frequency of the last of the 4096 tones. The IFFT circuit 12 thus generates samples at 35.228 MHz. These samples are provided to a decimator 30 which provides only every 16th sample to digital-to-analog converter 14. Digital-to-analog converter 14 then operates 16 times slower, i.e. at 2.208 MHz. Of course, the cut-off frequency of the low-pass filters 16 and 22 is adapted to the frequency of the digital-to-analog converter 14.

The analog-to-digital converter 24 is clocked to sample the received signal 16 times slower, i.e. at 2.208 MHz, and the samples are provided to an interpolator 32 which generates the missing samples to provide to FFT circuit 20 at 35.228 MHz.

With the above example, the power consumed by converters 14 and 24 is substantially reduced. This power consumption will be further reduced if the ADSL-Lite standard is used with the system.

When the system is used at its highest transmission rate, the decimator 30 and the interpolator 32 are bypassed as shown by switches, and the analog-to-digital converter 24 is clocked at the same speed as the IFFT and FFT circuits, i.e. 35.228 MHz in the example.

A purpose of a second embodiment of the invention is to further reduce the power consumption when the system is used at lower transmission rates.

In order to reduce the power consumption, it would be useful to also adapt the operating frequency of the IFFT and FFT circuits to the transmission rate effectively used, like the clock frequency of analog-to-digital converter 24 in figure 6. However, by changing the operating frequency of the IFFT and FFT circuits, the spacing of the tones is also changed, which is not desired.

To avoid this, the invention provides IFFT and FFT circuits of variable size, which is equivalent to making variable the number of tones used by the system. Then, if the size of the IFFT an FFT circuits is reduced by a factor k, it is sufficient to reduce the operating speed of the IFFT and FFT circuits by the same factor k for maintaining the spacing between the tones. In the example of figure 6, the number of tones will be reduced by a factor 16, whereby the IFFT and FFT circuits would operate 16 times slower, i.e. at 2.208 MHz, the same frequency as analog-to-digital converter 24. Decimator 30 and interpolator 32 are unnecessary.

With this system, the total power consumption will be substantially proportional to the effective transmission rate used on the system.

In contrast to what could be expected, making variable the number of inputs or outputs of an IFFT or FFT circuit is particularly simple if the number remains a power of 2.

Figure 7 schematically illustrates an IFFT circuit of a conventional pipeline type, modified according to the

invention for making the number of inputs variable. The IFFT circuit comprises 5 pipelined radix-4 stages 34 followed by a last stage 36 which may be switched between radix-2 and radix-4. The number of frequency domain inputs of the IFFT circuit is equal to the product of the radices of the stages. If the last stage is a radix-2, the IFFT circuit has 2048 inputs, whereas if the last stage is a radix-4, the IFFT circuit has 4096 inputs.

Preferably, the last stage 36 can be switched between a radix-4 or radix-2 operation mode by a switch signal R2. For this purpose, the stage is a full radix-4 and, for operating in radix-2 mode, suitable elements of the stage are bypassed.

Each stage receives and provides complex coefficients at the digital data transmission rate. Each complex coefficient, corresponding at the input of the first stage to one data word, has a real part and an imaginary part which are processed in two respective cycles, hence the operating frequency of the IFFT circuit is twice the data transmission rate. The operating frequency is set by a clock signal CK.

A radix-4 stage operates on 4 consecutive coefficients whereas a radix-2 stage only operates on 2 consecutive coefficients. Each coefficient provided by the last stage 36 is converted into two time domain samples by a complex to real converter 38.

The number of inputs corresponding to each stage is indicated in figure 7 at the bottom of the stages, a first value being the number of inputs when the last stage 36 is a radix-2, and a second value being the number a inputs when the last stage 36 is a radix-4. It thus clearly appears that the number of inputs of the IFFT circuit is selectable by bypassing one or several first stages of the circuit and by suitably selecting the radix of last stage 36.

For the ADSL-Lite standard, the first two stages 34 of the IFFT circuit are bypassed by a multiplexer 40, the radix

of the last stage 36 is chosen equal to 2, and the clock CK has a frequency of 1.104 MHz.

For the ADSL standard, the first two stages 34 of the IFFT circuit are also bypassed by multiplexer 40, the radix of the last stage 36 is chosen equal to 4, and the frequency of clock CK is chosen equal to 2.208 MHz.

For a VDSL transmission with 2048 tones according to figure 5, none of the stages is bypassed, the radix of the last stage 36 is chosen equal to 2, and the frequency of clock CK is chosen equal to 17.664 MHz.

For a VDSL transmission with 4096 tones according to figure 5, none of the stages is bypassed, the radix of the last stage 36 is chosen equal to 2, and the frequency of clock CK is chosen equal to 17.664 MHz.

A VDSL-TDD transmission would be modified to use a maximum frequency of 17.664 or 35.328 MHz instead of 22 MHz.

For such a modified VDSL-TDD transmission with 512 tones, the first stage 34 is bypassed by a multiplexer 42, and the radix of last stage 36 is chosen equal to 2.

For a modified VDSL-TDD transmission with 256 tones, the two first stages 34 are bypassed by multiplexer 40, and the radix of last stage 36 is chosen equal to 4.

Finally, for the VDSL transmission of figure 5 with 4096 tones, none of the stages is bypassed, the radix of the last stage 36 is chosen equal to 4, and the frequency of clock CK is chosen equal to 35.328 MHz.

An FFT circuit with a selectable number of outputs is constructed in the same manner as the IFFT circuit of figure 7. The differences are that the first stage is preceded by a real to complex converter which provides the real and imaginary parts of each complex coefficient in reverse order. The initial order is re-established at the output of the last stage, which is not followed by a complex to real converter.

Further information on pipeline IFFT and FFT circuits can be found, for example, in "A Fast Single-Chip

Implementation of 8192 Points FFT", IEEE Journal of Solid State Circuits, Vol. 30, N°3, March 1995, Pidet, Castelain, Senn, Blanc.

It is devised, for VDSL-TDD and VDSL "Zipper" modems, that the tones will be used in an initial phase to transmit modem identification signatures. In other words, a transmitting modem, before establishing a communication, will send a signal conveying specific tones or "bare" carriers, chosen depending on the standard among the possible tones. The receiving modem will detect which tones are present in the signal and identify the standard accordingly. For this purpose, the receiving modem should be "tuned-in" on the transmitting modem from the start, i.e. use at least the tones used by the transmitting modem. Every 8th or every 4th tone of a VDSL Zipper modem is used by a VDSL-TDD modem, whereby such an identification phase is possible in both directions if only the 256 or 512 tones of the VDSL-TDD system are used for the signatures.

If an ADSL modem should send signatures using consecutive tones, a modem according to the invention should be consistent with figure 5, i.e. use a tone spacing of 4.3125 kHz. However, since the signatures are not yet standardized, it may be devised that an ADSL modem will send signatures using only every p^{th} tone, where p is a power of 2. In this case, a modem having variable size IFFT and FFT circuits according to the invention may initially use a tone spacing of 4.3125p kHz and 2048/p or 4096/p tones and be switched to use 128 or 256 tones with a spacing of 4.3125 kHz upon identifying a remote ADSL modem.

Figure 8 partially and schematically shows an architecture of a universal DSL modem incorporating IFFT and FFT circuits 12' and 20' as described above. Elements shown in previous figures are designated by same reference characters. The IFFT circuit 12' is preceded by a mapper 50 which associates complex coefficients to outgoing digital words. Circuit 19 which adds cyclic prefixes and cyclic suffixes to

the symbols provided by IFFT circuit 12' also achieves pulse shaping. A windowing or frequency weighted averaging is achieved at 52 on the data provided by time domain equalizer 26 to FFT circuit 20'. The output of FFT circuit 20' is successively processed by a frequency domain equalizer 54, a radio frequency interference canceller 56 and a demapper 58 which achieves the inverse function of mapper 50.

The IFFT and FFT circuits 12' and 20' are controlled by a controller 60 as described above in relation with figure 7. Controller 60 also sets the sampling frequency of analog-to-digital converter 24 at the operating frequency of the IFFT and FFT circuits. Moreover, controller 60 bypasses the time domain equalizer 26 and the radio frequency interference canceller 26, as shown by switches, when the number of tones used by the system is equal to 2048 or 4096.

Elements of the architecture of figure 8 which are not further described are conventional and can be found in modems for existing standards, such as ADSL and ADSL-Lite (disclosed in Standard T1.413).

Such alterations, modifications, and improvements are intended to be part of this disclosure, and are intended to be within the spirit and the scope of the invention. Accordingly, the foregoing description is by way of example only and is not intended to be limiting. The invention is limited only as defined in the following claims and the equivalent thereto.

What is claimed is:

CLAIMS

1. A digital subscriber line transmission system using QAM modulation on N = 2048 or 4096 tones spaced by 4.3125 kHz, characterized in that it has at least two operating modes:

- a VDSL standard operating mode where all N tones are used to convey significant values; and

- an ADSL standard operating mode where only the first n = 128 or 256 among the N tones are used to convey significant values.

2. The system of claim 1, characterized in that it comprises, on the transmitter side:

- an inverse fast Fourier transform (IFFT) circuit (12) having N frequency domain value inputs corresponding to said tones, among which only the first receive values corresponding to the n used tones, the remaining inputs being zeroed,

- a decimator (30) providing one sample for every r samples output by the IFFT circuit, with r = N/n, and

- a digital-to-analog converter (14) coupled between the decimator and a subscriber line (10).

3. The system of claim 2, characterized in that it comprises, on the receiver side:

- an analog-to-digital converter (24) sampling the signal on the subscriber line at a frequency F/r, where F is the operating frequency of the IFFT circuit;

- an interpolator (32) generating samples at frequency F from the samples provided by the analog-to-digital converter; and

- a fast Fourier transform (FFT) circuit operating at frequency F and receiving the samples from the interpolator through a time domain equalizer (26);

wherein, when all N tones are used, the time domain equalizer is bypassed.

4. The system of claim 1, comprising, at a transmitter side, an IFFT circuit (12') having:

ART 34 AMDT

- a number of frequency domain inputs selectable at least among values N and n; and
- an operating frequency selectable at least among two values F and fn proportional, respectively, to the frequency of the last of the N tones and the last of the n tones.

5. The system of claim 4, characterized in that it comprises, at a receiver side, an FFT circuit (20') having:

- a number of frequency domain outputs selectable at least among values N and n; and
- an operating frequency selectable at least among values F and fn.

6. The system of claim 5, characterized in that each of the IFFT and FFT circuits includes five radix-4 stages (34) and a last stage (36) having a radix selectable among 2 and 4, all connected to operate in pipeline mode, the desired number of frequency domain inputs or outputs of the circuit being selectable by bypassing an appropriate number of stages and by selecting the radix of the last stage.

MULTISTANDARD DMT DSL TRANSMISSION SYSTEM

Abstract

A digital subscriber line transmission system using QAM modulation on several equally spaced discrete tones, uses, at a high transmission rate, N = 2048/p or 4096/p tones spaced by 4.3125p kHz, where p is a power of 2.

Fig. 5

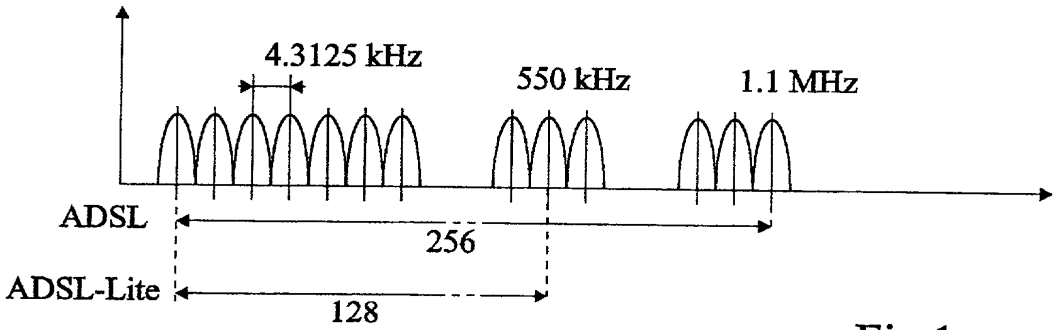

Fig 1

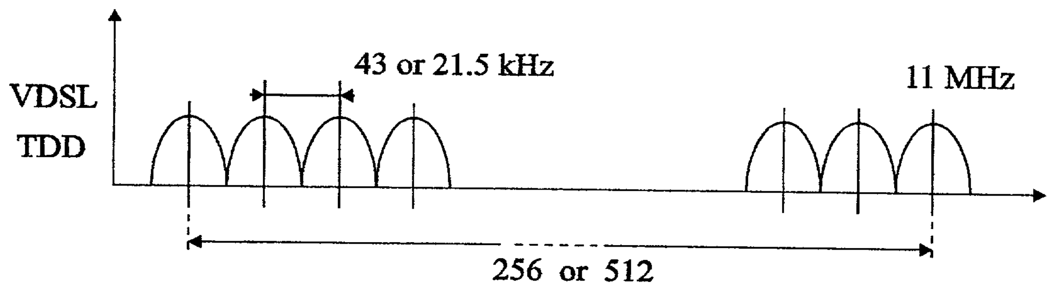

Fig 2

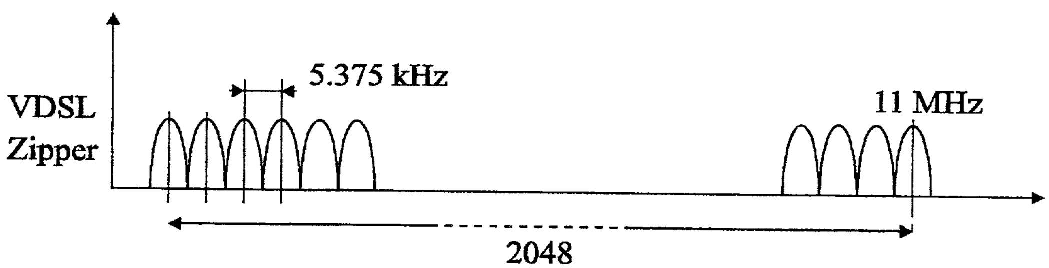

Fig 3

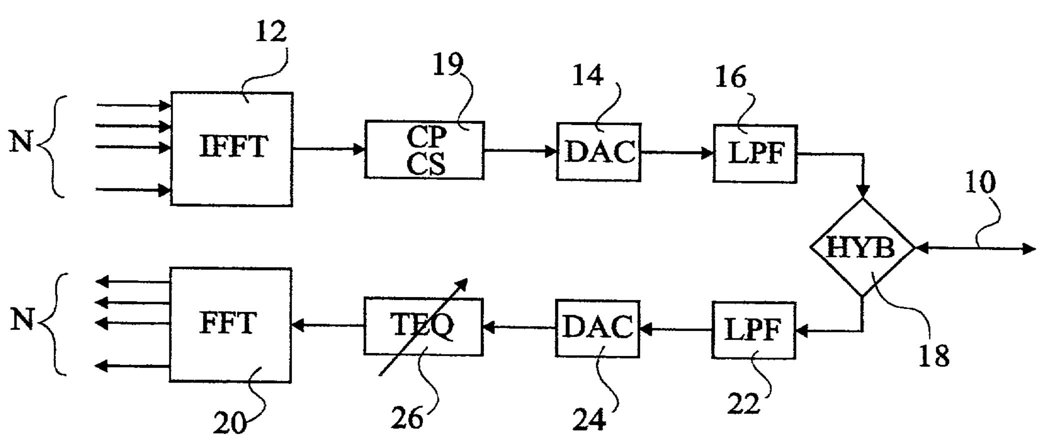

Fig 4

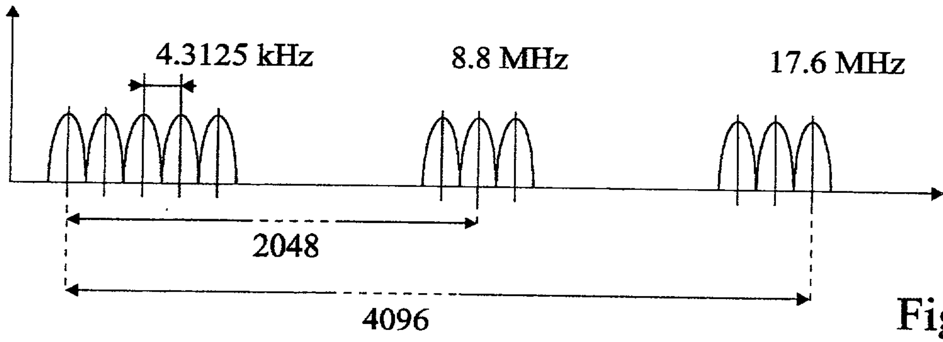

Fig 5

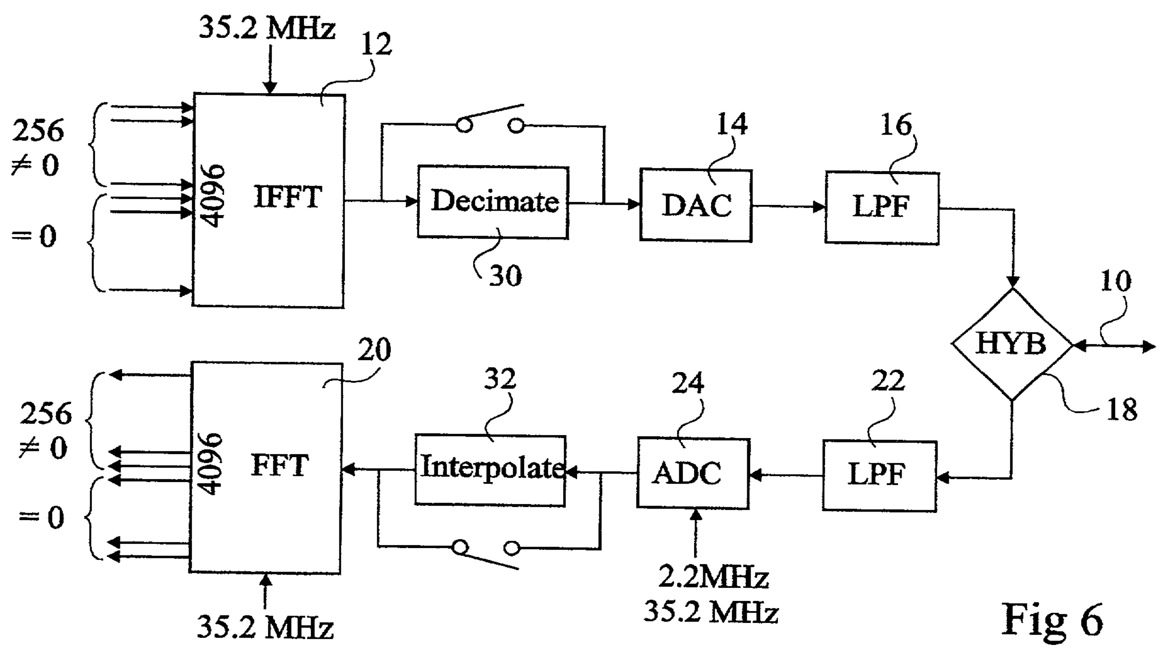

Fig 6

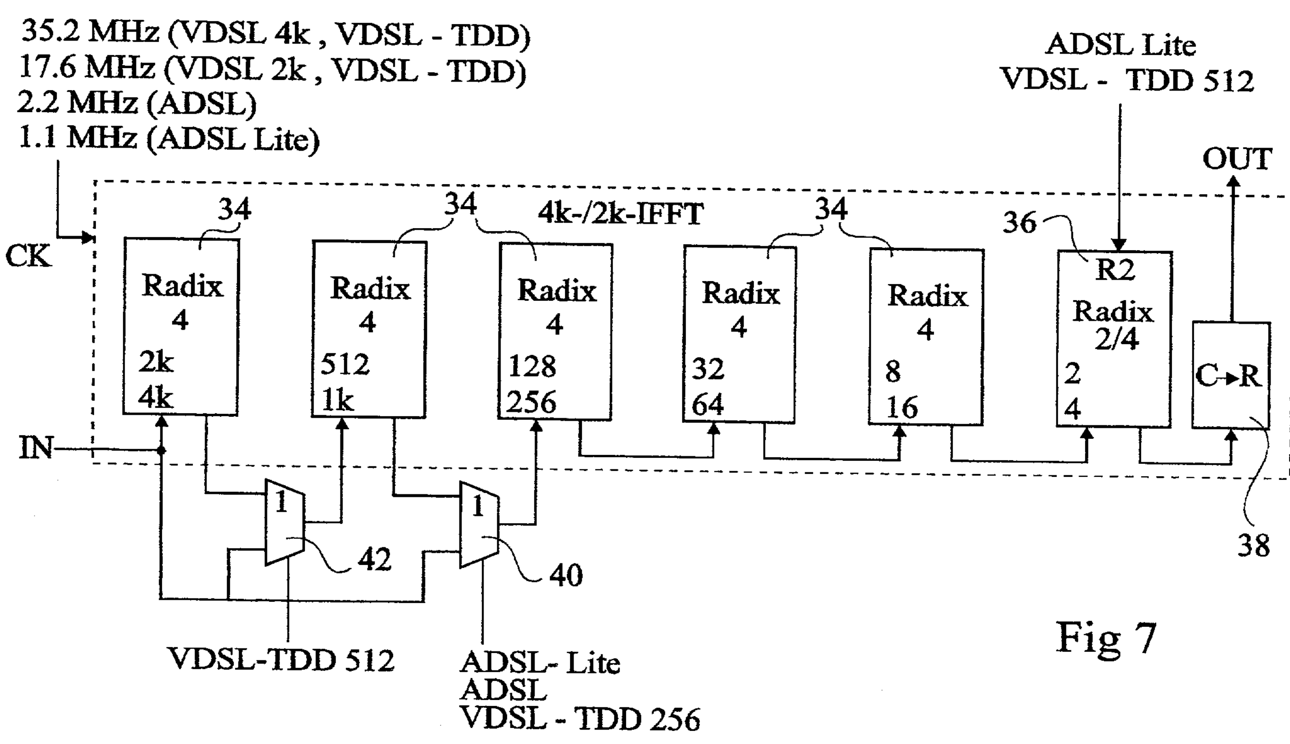

Fig 7

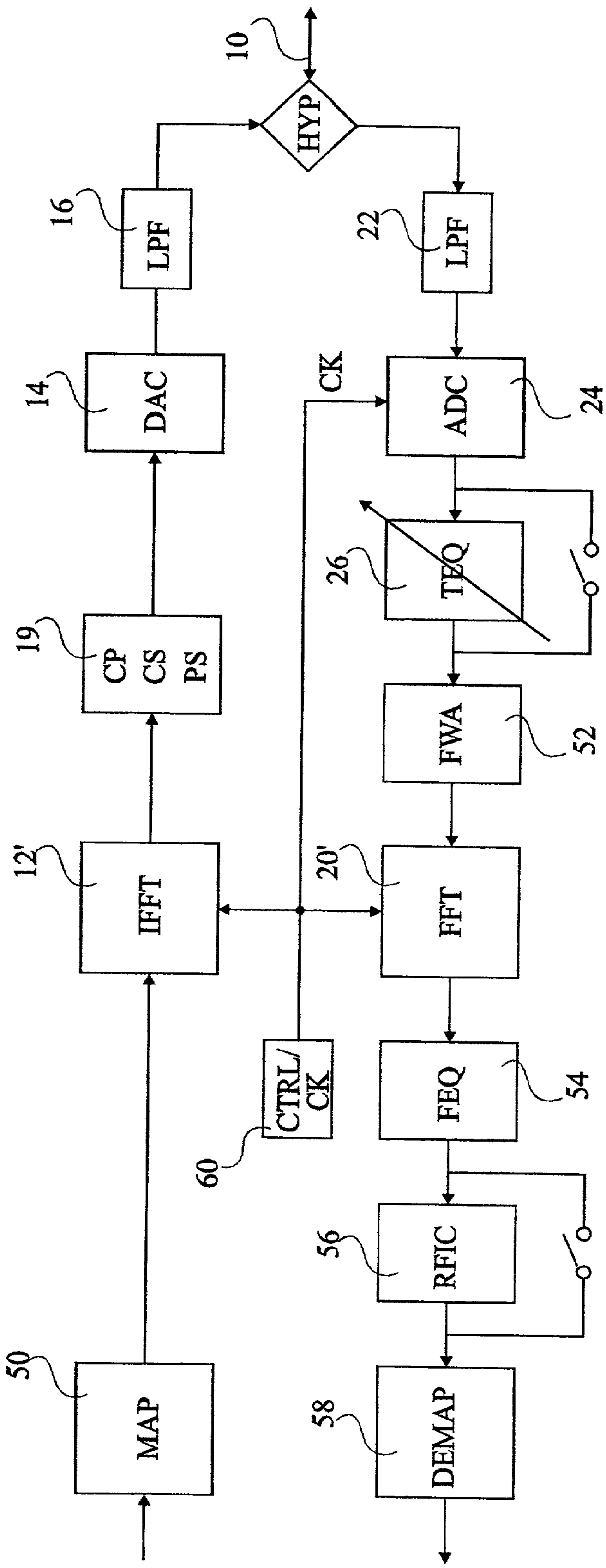
10
HYP
16
LPF
22
LPF
14
DAC
CK
ADC
24
26
TEQ
19
CP
CS
PS
FWA
52
12'
IFFT
20'
FFT
CTRL/
CK
60
FEQ
54
56
RFIC
50
MAP
58
DEMAP

Fig 8

Declaration and Power of Attorney for Patent Application

Déclaration et Pouvoirs pour Demande de Brevet

French Language Declaration

En tant que l'inventeur nommé ci-après, je déclare par le présent acte que:

As a below named inventor, I hereby declare that:

Mon domicile, mon adresse postale, et ma nationalité sont ceux figurant ci-dessous à côté de mon nom.

My residence, post office address and citizenship are as stated next to my name.

Je crois être le premier inventeur original et unique (si un seul nom est mentionné ci-dessous), ou l'un des premiers co-inventeurs originiaux (si plusieurs noms sont mentionnés ci-dessous) de l'objet revendiqué, pour lequel une demande de brevet a été déposée concernant l'invention intitulée:

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

MULTISTANDARD DMT DSL TRANSMISSION SYSTEM ✓

et dont la description est fournie ci-joint à moins que la case suivante n'ait été cochée:

the specification of which is attached hereto unless one of the following boxes is checked:

☒ a été déposée le 23 MAI 2001 ✓ sous le numéro de demande des Etats-Unis ou le numéro de demande international PCT 09/856 738 ✓

☒ was filed on 23 MAY 2001 as United States Application Number or PCT International Number 09/856 738

☐ les specifications portant le dossier de l'avocat numero ______

et modifiée le ______ (le cas échéant).

☐ the specification of which bears attorney docket No. ______

and was amended on ______ (if applicable).

Je déclare par le présent acte avoir passé en revue et compris le contenu de la description ci-dessus, revendications comprises, telles que modifiées par toute modification dont il aura été fait référence ci-dessus.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

Je reconnais devoir divulguer toute information pertinente à la brevetabilité, comme défini dans le Titre 37, §1.56 du Code fédéral des réglementations.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56.

French Language Declaration

Je revendique par le présent acte avoir la priorité étrangère, en vertu du Titre 35, §119(a)-(d) ou § 365(b) du Code des Etats-Unis, sur toute demande étrangère de brevet ou certificat d'inventeur ou, en vertu du Titre 35, § 365(a) du même Code, sur toute demande internationale PCT désignant au moins un pays autre que les Etats-Unis et figurant ci-dessous et, en cochant la case, j'ai aussi indiqué ci-dessous toute demande étrangère de brevet, tout certificat d'inventeur ou toute demande internationale PCT ayant une date de dépôt précédant celle de la demande à propos de laquelle une priorité est revendiquée.

I hereby claim foreign priority under Title 35, United States Code, §119(a)-(d) or § 365(b) of any foreign applications(s) for patent or inventor's certificate, or § 365(a) of any PCT International application which designated at least one country other than the United States, listed below, and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed:

Prior foreign application(s)
Demande(s) de brevet antérieure(s)

98410131.1	EUROPE	24 November 1998	
(Number) (Numéro)	(Country) (Pays)	(Day/Month/Year Filed) (Jour/Mois/Année de dépôt)	Priority not claimed / Droit de priorité non revendiqué ☐
(Number) (Numéro)	(Country) (Pays)	(Day/Month/Year Filed) (Jour/Mois/Année de dépôt)	☐

Je revendique par le présent acte tout bénéfice, en vertu du Titre 35 §119(e) du Code des Etats-Unis, de toute demande de brevet provisoire effectuée aux Etats-Unis et figurant ci-dessous.

I hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below.

(Application No.) (N° de demande) — (Filing Date) (Date de dépôt)

(Application No.) (N° de demande) — (Filing Date) (Date de dépôt)

Je revendique par le présent acte, le bénéfice, en vertu du Titre 35 § 120 du Code des Etats-Unis, de toute demande de brevet effectuée aux Etats-Unis, ou en vertu du Titre 35, § 365(c) du même Code, de toute demande internationale PCT désignant les Etats-Unis et figurant ci-dessous et, dans la mesure où l'objet de chacune des revendications de cette demande de brevet n'est pas divulgué dans la demande antérieure américaine ou internationale PCT, en vertu des dispositions du premier paragraphe du Titre 35, § 112 du Code des Etats-Unis, je reconnais devoir divulguer toute information pertinente à la brevetabilité, comme défini dans le Titre 37, § 1.56 du Code Fédéral des réglementations, dont j'ai pu disposer entre la date de dépôt de la demande antérieure et la date de dépôt de la demande nationale ou internationale PCT de la présente demande:

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) or § 365(c) of any PCT international application(s) designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application:

PCT/EP99/09475	November 24, 1999	
(Application No.) (N° de Demande)	(Filing Date) (Date de Dépôt)	(Status)(Patented, pending abandoned) (Statut)(breveté, en cours d'examen, abandonné)
(Application No.) (N° de Demande)	(Filing Date) (Date de Dépôt)	(Status)(Patented, pending abandoned) (Statut)(breveté, en cours d'examen, abandonné)

Je déclare par le présent acte que toute déclaration ci-incluse est, à ma connaissance, véridique et que toute déclaration formulée à partir de renseignements ou de suppositions est tenue pour véridique; et de plus, que toutes ces déclarations ont été formulées en sachant que toute fausse déclaration volontaire ou son équivalent est passible d'une amende ou d'une incarcération, ou des deux, en vertu de la Section 1001 du Titre 18 du Code des Etats-Unis, et que de telles déclarations volontairement fausses risquent de compromettre la validité de la demande de brevet ou du brevet délivré à partir de celle-ci.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

French Language Declaration

POUVOIR: En tant que l'inventeur cité, je désigne par la présente l'(les) avocat(s) et/ou agent(s) suivant(s) pour qu''il(s) poursuive(nt) la procédure de cette demande de brevet et traite(nt) toute affaire s'y rapportant avec l'Office des brevets et des marques: *(mentionner le nom et le numéro d'enregistrement).*

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. *(list name and registration number)*

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Signature de l'inventeur — Date 19.7.01	Inventor's signature — Date
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Nom complet du second co-inventeur, le cas échéant 2-00 Gérard FARGERE	Full name of second or joint inventor
Signature de l'inventeur — Date 24/07/01	Inventor's signature — Date
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Nationalité French	Citizenship
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110256.1

French Language Declaration

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Firma del quarto inventore Date	Inventor's signature Date
Domicle	Residence
Nationalité	Citizenship
Addresse Postale	Post Office Address
Nom complet du cinquièine co-inventor, le cas échéant	Full name of fifth joint inventor, if any
Firma del secondo inventore Date	Inventor's signature Date
Domicle	Residence
Nationalité	Citizenship
Addresse Postale	Post Office Address
Nom complet du sixièine co-inventor, le cas échéant	Full name of sixth joint inventor, if any
Firma del sesto inventore Date	Sixth inventor's signature Date
Domicle	Residence
Nationalité	Citizenship
Addresse Postale	Post Office Address